LABORATORY INVESTIGATIONS AND PERFORMANCE EVALUATION OF STONE MATRIX ASPHALT

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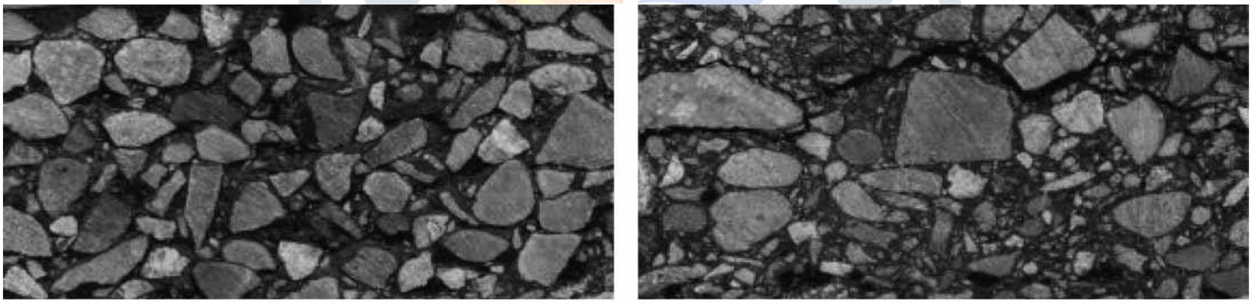
Abstract: In today's world, road network of any country is of great importance for its economic growth. The aim of this study is to evaluate the performance of Stone Matrix Asphalt (SMA) by conducting Marshall Stability test and to find out the optimum binder content (OBC) using volumetric analysis and calculate the drain down characteristics of an uncompacted mixture of Stone Matrix Asphalt by conducting the Drain Down Test as per ASTM D 6390.

Keywords: SMA, OBC, Marshall Stability, Draindown.

1. INTRODUCTION

There are 3 types of asphalt surfaces i.e. Dense Graded Asphalt (DGA); Open Graded Asphalt (OGA); Stone Matrix Asphalt (SMA). The main difference between these three surfaces is the proportion of different aggregates, amount of binder content and presence of any other material additive.

The SMA contains about 70-80 percent of coarse aggregate in the mix whereas, conventional mixes contain about 40-60 percent coarse aggregate. In SMA mixture, the binder content is more than 6% but on the other hand, conventional mixes contains about 5-6%. The third difference between these mixes is the use of stabilized additive in the SMA mixture to prevent drain down. Stone Matrix Asphalt (SMA) is made up of gap graded aggregate generally with a higher binder content, filler and stabilized fiber. SMA has high strength and performance compared to other asphalt surfaces.



SMA HMA

2. Materials Used

2.1 Coarse Aggregates: Coarse aggregates are obtained from the stone crusher situated at Anandpur Sahib, Punjab. They have to retained on 2.36 mm IS sieve as per IRC:SP: 79-2008.

2.2 Fine Aggregate: They are also obtained from the stone crusher situated at Anandpur Sahib, Punjab.

2.3 Mineral Filler: Stone Dust is used as a mineral filler for the preparation of SMA mixture as per IRC:SP: 79-2008.

2.4 Bitumin: Viscosity Grade VG-30 is used as a binder for fiber stabilized SMA.

2.5 Stabilizer Additive: Natural cellulose fiber is used as an additive with a dosage of 0.3% by weight of total mix.

3. Marshall Method of Mix Design- An Introduction

Bruce Marshall of the Mississippi Highway Department in 1939 brought the marshall mix design methods which was then amplified by the U.S. Army. The Marshall method solicits the optimum binder content at a desired density that gratifies minimum stability and ambits the flow value.

3.1 Marshall Mix Design Procedure

The Marshall Mix design method consists of 5 basic steps:

1. Aggregate and binder selection.
2. Sample preparation (including compaction).
3. Stability determination.
4. Density and voids calculations i.e. volumetric analysis.
5. Optimum asphalt binder content selection.

3.1.1 Aggregate Selection and binder selection

A typical aggregate evaluation for use with Marshall Mix design methods includes three basic steps:

- Determination of aggregate physical properties such as strength, particle shape and size, etc.
- Determination of aggregate gradation, specific gravity and absorption.
- Perform blending calculations to achieve the mix design aggregate gradation**.**

The assay procedure and the binder selection are not common in the Marshall test. To determine the appropriate binder/optimum binder content, each enumerated organization adopts their own method with some enhancements.

3.1.2 Sample Preparation

In marshall method, different aggragtes like coarse aggregates, fine aggregates and filler material are proportioned in such a way to fulfill the desired type of bituminous mix. Then, by evaluating each proportion, optimum binder content can be achieved. Samples are prepared at the increment of 0.5% by weight of mix and 3 samples are prepared for each binder content for calculating the optimum binder content.

Each sample is prepared at a mixing temperature of about 160 ^{o}C in a compaction mould assembly with a help of rammer which are kept pre heated at a temperature of 95-150 ^{o}C. The prepared sample should ideally be of 101.6 mm diameter and 63.5 mm thickness. However correction factors can be applied if the dimensions are not in the specified ranges. The specimen is compacted by giving 75 blows on each face of the sample by a hammer of weight 4.5 kg and a drop of 457 mm. Load is applied perpendicular to the axis of the specimen at a constant deformation rate of 51 mm per minute.

3.1.3 The Marshall Stability and Flow Test

This test predicts the performance measure for the Marshall Mix Design Method. The maximum load that the specimen can withstand at a loading rate of 51 mm/minute is known as ‘Stability Value’ and the vertical deformation of the specimen corresponding to that maxi mum load is known as ‘Flow Value’ of the specimen.

3.1.4 Density and Voids Analysis

Mix design methods uses density and voids to determine the optimum binder content. Different measures of density are taken in the Marshall Mix design:

- **Bulk specific gravity (G_{mb}):** this can be determined by taking the weight of Marshall Sample in air and then in water. Saturated Surface Dry weight (SSD) is also taken by taking sample weight in air after taking weight in water so that the voids only on the surface of sample are filled. G_{mb} is then calculated as:

$$G_{mb} = \frac{Weight\ in\ air}{SSD - Weight\ in\ water}$$

- **Theoretical maximum specific gravity (TMD, G_{mm}):** It is the specific gravity of a bituminous mix not including air voids. Thus, if all the air voids are excluded from the bituminous mix, the integrated specific gravity of the remaining aggregate and asphalt binder will be the theoretical maximum specific gravity. This can be determined either by using formula or by determining density of un-compacted mix using pycnometer method. The formula does not account for the bitumen absorbed by the aggregates although can be used with negligible error:

$$G_{mm} = \frac{100 + c}{\frac{a}{X} + \frac{b}{Y} + \frac{c}{Z}}$$

Where
a, b= fraction of different aggregate blends in %,
c= Bitumen content in %
X, Y= Specific Gravity of a and b aggregates
Z= specific gravity of bitumen.

The volumetric parameters of the HMA can be determined on the basis of these two densities. Distinctive expressions for voids are as follows:-

- **Air voids (V_a)**, sometimes expressed as voids in the total mix (VTM):

$$V_a = \frac{G_{mm} - G_{mb}}{G_{mm}}$$

- **Voids in the mineral aggregate (VMA):** It is the volume of voids in aggregates given by:

$$VMA = V_a + V_b$$

$$V_b = \frac{Bitumen\ Content * G_{mb}}{Z}$$

- **Voids filled with bitumen (VFB):** Voids in the aggregate framework filled with bitumen and is given by:

$$VFB = \frac{V_b}{VMA} \times 100$$

3.1.5 Selection of Optimum Binder Content

The optimum binder content is finally determined based on the results of Density analysis, air void analysis, Stability and flow values.selected based on the combined results of Marshall Stability and flow, density analysis and void analysis. Optimum asphalt binder content can be determined in the following procedure:

a) Plot the following graphs:

- Asphalt binder content vs. density.
- Asphalt binder content vs. Marshall Stability.
- Asphalt binder content vs. flow.
- Asphalt binder content vs. air voids.
- Asphalt binder content vs. VMA
- Asphalt binder content vs. VFB.

b) Calculate the optimum binder content for the mix design with the help of graphs oracular to the above step by taking the average value of the bitumen content.
  - Binder content cognated to maximum stability.
  - Binder content cognated to maximum density.
  - Binder content cognated to the 4% of air voids (V_a) in the total mix.

The stability value, flow value, and VFB are checked with Marshall Mix design specification chart. For heavy moving loads, the mixes having high Stability nad Flow value are not advisable because of the development of cracks in the pavement.

4. EXPERIMENTAL INVESTIGATION

4.1 Mix Design of SMA Layer

After finalizing the gradation, the next step is to determine the Optimum Binder Content (OBC) using Marshall Mix Design method. 9 Marshall Samples are casted at binder content of 6%, 6.5%, 6.75% and 7% (by weight of mix), (3 samples at each binder percentage). A fiber content of 0.3% by weight of mix is selected for all samples. The mixing temperature is 160^0C and the compaction temperature is 140^0C.

For casting the Marshall Sample 1200 grams of aggregate are taken and mixed with corresponding bitumen content by weight of mix and 0.3% fiber by weight of mix at a mixing temperature of about 160^0C. The mixing of aggregates and bitumen should be done properly so that every aggregate is coated with bitumen properly. The Marshall mould, collar and the hammer are preheated in the oven. The prepared mix is filled in the mould. The specimen is compacted by giving 50 blows on each face of the sample by a hammer of weight 4.5 kg and a drop of 457 mm. Load is applied perpendicular to the axis of the specimen at a constant deformation rate of 51 mm per minute.

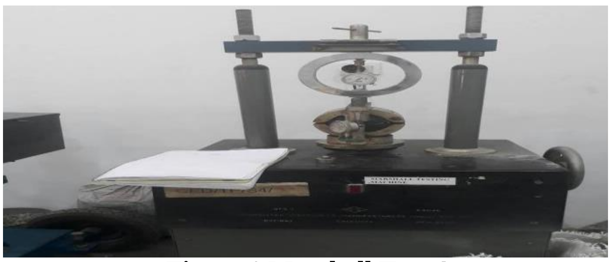


Figure 1 Marshall Test Apparatus

Figure 2 Marshall Sample of SMA Mixture

The thickness of each specimen should be 63.5mm and a diameter of 101.6mm. After preparing the Marshall samples, they are left undisturbed for 24 hours and then the samples are removed from their moulds.

Table 1 Properties of Coarse Aggregate

Property	Results	IRC:SP: 79-2008 requirements
0Aggregate Impact Value	18.5 %	24 % max.
Los Angles Abrasion Value	16.40 %	25 % max.
Water Absorption	0.4 %	2 % max.
Specific Gravity Test	2.638	-

Table 2 Aggregate Gradation for SMA

SMA Designation	13 mm SMA
Course where used	Wearing Course
Nominal Aggregate Size	13 mm
Nominal Layer Thickness	40-50 mm
IS Sieve (mm)	Cumulative % by weight of total agg. Passing
26.5	-
19	100
13.2	90-100
9.5	50-75
4.75	20-28
2.36	16-24
1.18	13-21
0.6	12-18
0.3	10-20
0.075	8-12

Table 3 SMA mix Requirements

Mix Design Parameters	Requirement
Air Void Content, %	4.0
Bitumen Content, %	5.8 min.
Celluloid fibers	0.3 % min. by weight of total mix
Voids in Mineral Aggregates (VMA), %	17 min.
VCA mix, %	Less than VCA (dry rodded)
Asphalt Drain down, %	0.3 max.
Tensile Strength Ratio, %	85 min.

4.2 Volumetric and Marshall Properties

After the Marshall samples are removed from their moulds, the density of each sample is determined. Based on this data, volumetric analysis of the sample is done and Voids in Mineral Aggregates (VMA), Voids Filled with Bitumen (VFB), and percentage Air Voids are calculated.

Further the Marshall Stability and Flow values are determined. Marshall Test is conducted in order to determine the resistance to plastic deformation of cylindrical specimen when loaded at its periphery at a rate of 50.8 mm/minute. The test procedure is as given in ASTM D 6927. Before testing for its stability and flow values the Marshall Samples are kept in a water bath at 60 ^{0}C for 30-40 minutes. Appropriate correction factors are applied to the Marshall Stability values if the thickness of the Marshall Sample is not 63.5mm or its volume is not in the range of 509-522 cm^3.

4.3 Drain Down Test

4.3.1 Introduction

This test is done specially for the mixture such as Stone Matrix Asphalt and Open Graded Asphalt in which we calculate the amount of binder drain down of an uncompacted mix. Drain Down is defined as the portion of mix which leaves itself from the sample and flows downwards when it is held at high temperatures. This problem can be faced during the transport, placement and production storage of the mixture and is significant for those mixtures having high coarse aggregate content i.e. Stone Matrix Asphalt in which voids are much larger in an uncompacted mix which results in high drain down as comparison to other conventional mixes.

4.3.2 Procedure

Drain Down test is conducted as per AAHTO T305 on the mixture prepared at optimum binder content and is poured into the wire basket having a sieve cloth of size 6.3 mm.

Then a catch plate is taken and weighed and the basket with the mixture poured in it is also weighed. Now the basket is placed over the catch plate and kept in an oven for 1 hour $\pm$ 5 min. at 120 ^{o}C to 175 ^{o}C with $\pm$ 2^{o}C of the set temperature.

After 1 hour, the binder from the mixture is drained into the catch plate and is again weighed. Now calculate the drain down as a percentage of the mass retained to the total mass of the mixture.

Drain Down (%) = {(Z-Y)/(X-W)}×100

Where,

W = Mass of empty wire basket, g

= 306 g

X = Mass of wire basket with sample, g

= 1584 g

Y= Mass of empty plate, g

= 220 g

Z = Mass of catch plate with drained sample, g

= 222 g

Therefore,

Drain Down (%) = $\frac{222-220}{1584-306} \times 100$

= **0.156 %**

Figure 3 Empty Wire Basket and Catch Plate

Figure 4 wire Basket with SMA mix in Oven

Table 4 Marshall Properties of SMA Mixture

Bitumen Content	Sample No.	Average Thickness (mm)	Average diameter (mm)	Volume (cc)	Marshall Stability (Kg)	Correction Factor	Corrected Marshall Stability (Kg)	Marshall Flow (mm)	Marshall Coefficient

6%	1	70.25	101	562.55	800	0.86	688	4	
	2	71	101	568.55	800	0.86	688	2.3	
	3	70.75	101	566.55	800	0.86	688	3.3	
	Average						**688.00**	**3.20**	2.15
6.50%	4	71	101	568.55	1200	0.86	1032	3.8	
	5	71.25	101	570.55	1150	0.86	989	3.5	
	6	70.25	101	562.55	1150	0.86	989	3.3	
	Average						**1003.33**	**3.53**	2.84
6.75%	7	70	101	560.54	1120	0.86	963.2	3.5	
	8	69	101	552.54	1140	0.89	1014.6	5	
	Average						**988.90**	**4.25**	2.33
7.00%	10	71	101	568.55	900	0.86	774	4.9	
	11	70	101	560.54	950	0.86	817	6.4	
	Average						**795.50**	**5.65**	1.41

MARSHALL TEST DATA

Source/Location :-	Patiala				Compaction Level	50 Blows on Each Face
Type of Mix :-	*SMA Grading 1*				Mixing Temp. :-	160 ^{0}C
Blending Proportions :-	Aggregate	**CA**	**FA**	**Filler**	Compaction Temp. :-	140 ^{0}C
	Proportion	**76**	**14**	**10**		
	Specific Gravity	**2.638**	**2.612**	**2.581**	Sp. Gravity of Bitumen (G_b)	1.01

Specimen No.	% Bitumen By weight of	Mass in (gms) Air	Wt. In Water	SSD in Air	Bulk Volume (CC)	Gmb (gm/cc)	Max. Theoretical Density	% Air Voids	% Vb	% VMA	% VFB
1	**6.38**	1265.00	700.00	1276.00	576.0	2.196	2.398	8.476	13.9	22.34	62.06
2		1266.00	700.00	1278.00	578.0	2.190					
3		1266.00	700.00	1276.00	576.0	2.198					
	= **Average Bulk Density in (gm/cc)**					**2.195**					
4	**6.95**	1274.00	720.00	1280.00	560.0	2.275	2.381	4.200	15.7	19.89	78.89
5		1274.00	725.00	1280.00	555.0	2.295					
6		1272.00	720.00	1280.00	560.0	2.271					
	= **Average Bulk Density in (gm/cc)**					**2.281**					
7	**7.23**	1262.00	725.00	1266.00	541.0	2.333	2.372	2.157	16.6	18.77	88.51
8		1254.00	715.00	1258.00	543.0	2.309					
9											
	= **Average Bulk Density in (gm/cc)**					**2.321**					
10	**7.50**	1272.00	730.00	1278.00	548.0	2.321	2.364	2.363	17.1	19.50	87.88
11		1274.00	725.00	1280.00	555.0	2.295					
12											
	= **Average Bulk Density in (gm/cc)**					**2.308**					

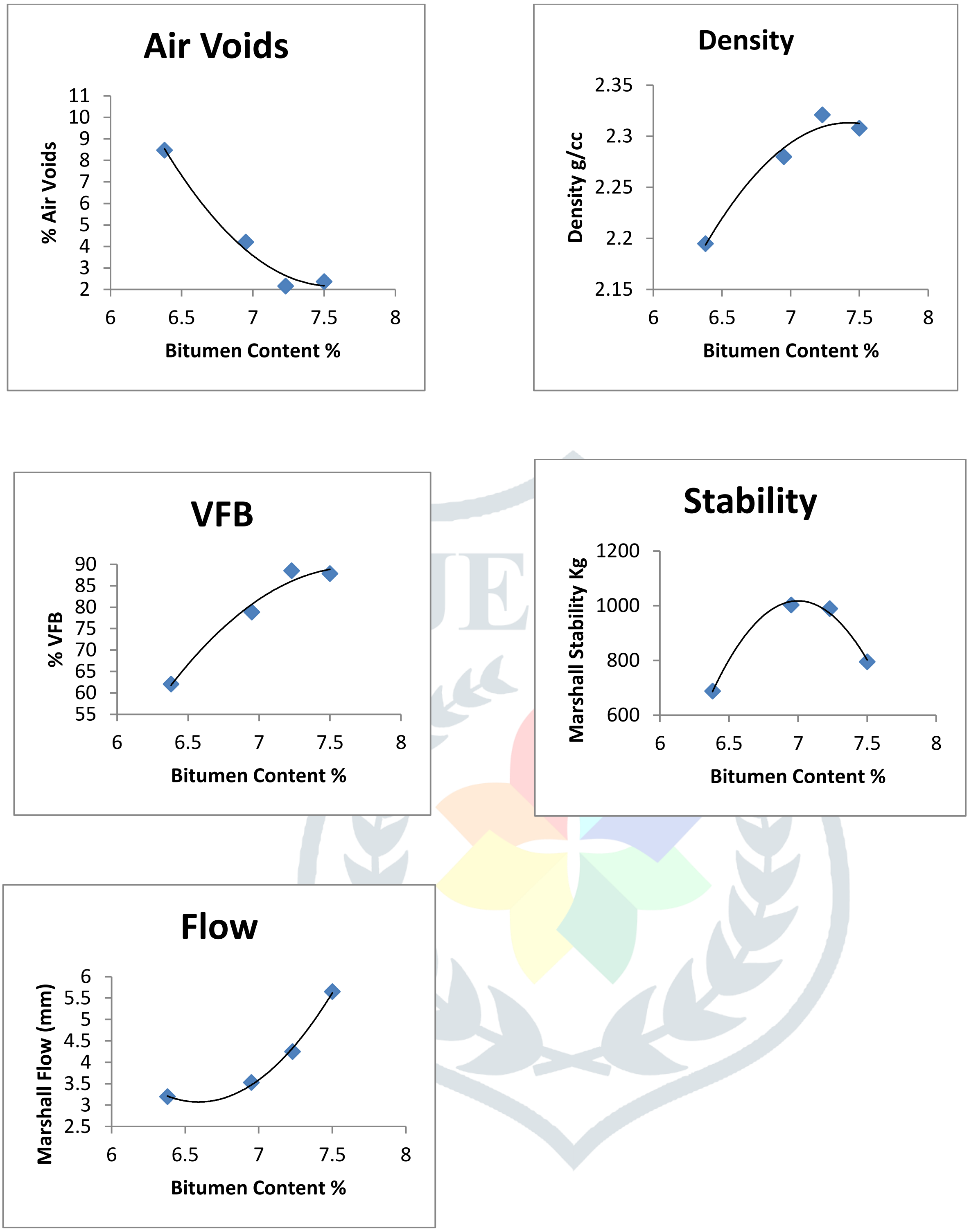


Figure 5 Graphs between Binder Content and Volumetric Properties

6. Results and Discussion

From the above calculations and graphs, the optimum binder content comes out to be 6.6% by weight of total mix corresponding to the maximum Density graph, maximum Stability graph and 4% Air Void Content. Drain Down comes out to be 0.156 %.

Table 5 Volumetric and Marshall Properties at OBC

Property	SMA Mixture
OBC, (%)	6.6
VMA, (%)	19.41
VFB, (%)	83.17
MS (kg)	1002.2

FV (mm)	3.6
MQ (kg/mm)	278.39
Drain Down (%)	0.156

7. Conclusions

i. From above test, we conclude that SMA mix requires higher bitumen content as comparison to other bituminous mixes.
ii. Voids in Mineral Aggregate (VMA) are higher than other conventional mixes due to the presence of high proportion of coarse aggregate in the mixture.
iii. Marshall Stability comes out to be 1002.2 kg at OBC and the SMA mixture has high strength and performance than other bituminous mixes.
iv. Drain down comes out to be 0.156 % which is nearly half of the maximum permissible value i.e. 0.3 % and it is due to the presence of natural cellulose fiber.

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